Deformable Aerodynamic Profile

BACKGROUND AND SUMMARY OF THE INVENTION

[0001] This application claims the priority of German patent document 103 04 530.9, filed February 4, 2003 (PCT International Application No. PCT/DE2004/000162, filed February 3, 2004) the disclosure of which is expressly incorporated by reference herein.

[0002] The present invention relates a deformable aerodynamic profile member ~~according to the preamble of Claim 1~~.

[0003] Various arrangements and methods are known for adjusting and optimizing the buoyancy and flow resistance of a body with flow around it ~~, e.g.,~~ (*e.g.*, in the form of an aerodynamic profile), to adapt to various ambient conditions. Such aerodynamic profiles may include, for example, helicopter rotor blades, aircraft wings or turbine blades, to name but a few examples.

[0004] ~~A number of approaches are known from~~ In the field of aeronautical engineering, [[where]] deformation of a profile curvature of such aerodynamic ~~profiles is~~ profiled members has been is achieved mechanically by using different adjustment devices. However, gaps and hollow spaces then usually occur in the shell of the profile, which is a disadvantage for many applications.

[0005] To counteract this problem, German patent document DE 196 43 222 C2 ~~describes~~ discloses an arrangement in which the properties of flow around a body are modified by continuous deformation of an aerodynamic

profile having an elastically deformable shell, using an adjustment device integrated into the profile.

[0006] ~~Furthermore,~~ German patent document DE 197 09 917 C1, on the other hand, describes a device for controlled deformation of a shell structure, having a number of bulging ribs, which are joined together by actuators to achieve a change in the curvature of an elastic component connected to the bulging ribs.

[0007] In addition, composite structures for producing and detecting deformation are known ~~from the state of the art; these structures~~ which have a plurality of piezoelectric fibers running in parallel [[(e.g.,]] (for example, United States Patent Nos. 5,869,189 and ~~United States Patent~~ 6,048,622). However, ~~it is a disadvantage here that these~~ such fibers are not only very expensive, and [[but]] are [[also]] relatively inefficient ~~because of~~ due to their great weight. Furthermore, suitable contacting of the piezoelectric fibers is necessary. Another ~~, and another~~ factor to be taken into account is achieving the most homogeneous possible field distribution, which is necessary for producing the piezoelectric effect. The electrodes required for this purpose may be provided, for example, by separate layers [[, i.e.,]] (*i.e.*, electrode layers), which can be integrated into the composite structure only with a corresponding extra technical expense.

[0008] When using this known composite structure to induce deformation, it is also a disadvantage that as a rule a high voltage is necessary ~~for triggering~~ to trigger the piezoelectric fibers. This means ~~not only~~ that a high energy demand is

~~necessary~~ generated, which makes the arrangement inefficient, ~~but also~~ and that a complex electronic control system is necessary. In addition, suitable safety provisions must be taken.

[0009] It is thus [[the]] an object of the present invention to create a deformable aerodynamic profile whose profile curvature can be varied in a technically simple and effective manner.

[0010] This and other objects and advantages are achieved by the ~~object is achieved by an~~ aerodynamic ~~profile~~ profiled member according to the invention, which has a front profile area and a rear profile area situated in the downflow. The profiled member is founded by shells on a ~~and is bordered by a shell on the~~ pressure side and on [[the]] a suction side, ~~converging~~ which converge at a rear edge of the profile. According ~~; this profile is characterized according~~ to [[this]] the invention, the profiled member ~~in that it~~ is equipped with d33 piezo actuators in at least some [[spots]] locations for its deformation, such that their change in length occurs essentially in the direction of the planes of the shells when acting upon by electricity.

[0011] ~~Due to the use and appropriate alignment of piezoelectric actuators with a~~ Because the so-called longitudinal ~~effect~~ (d33) effect [[(),]] (in which ~~where~~ the change in length of the piezoelectric material takes place in the direction of the electric field) ~~which~~ is known to be greater than the usual (d31) piezo effect ~~(d31 effect)~~ (in which the change in length is perpendicular to the electric field), a

more effective introduction of forces into the aerodynamic profile is possible <u>by an appropriate alignment of piezoelectric actuators</u>.

<u>[0012]</u> It is especially expedient to arrange the d33 piezo actuators on the pressure side and/or suction side of the shell. The shells are usually made of conventional construction materials and the d33 piezo actuators are attached, [[e.g.,]] <u>for example,</u> by adhesive bonding. However, mechanical fastening means <u>such as</u> [[(e.g.,]] clamping devices or screwing devices [[)]] may also be used for ~~fastening~~ <u>this purpose</u>. In addition, the shell provided with the piezo actuators may also be provided with a protective layer to protect the piezo actuators from impact, pressure, pulling or other external influences (including environmental factors).

<u>[0013]</u> According to another embodiment, the d33 piezo actuators are integrated into the shell on the pressure side and/or suction side. This configuration is preferred in so-called composite structures<u>,</u> which may be metallic<u>,</u> but may also be so-called MMCs (metal matrix composites). Likewise, the d33 piezo actuators may be integrated into composite fiber structures. One advantage [[here]] <u>of this arrangement</u> is that the piezo actuators are automatically protected.

<u>[0014]</u> Similarly, the ~~inventive principle~~ <u>invention</u> may also be applied to other floating bodies, which are attached with an articulated joint to the aerodynamic profile, ~~for example, e.g.,~~ <u>such as</u> control flaps. In this case the control flap is provided with d33 piezo actuators ~~and the d33 piezo actuators are~~

~~in turn~~ which are aligned so that their change in length takes place essentially in the plane of the flap when exposed to an electric current in a similar manner. A design in which the flap ~~provided~~ with d33 piezo actuators is connected to the rear profile edge of the aerodynamic profile with an articulated connection is particularly advantageous.

[0015] It is especially advantageous for the d33 piezo actuators to be used in the form of stacks of piezoelectric elements (so-called piezo stacks or "laminar" piezo actuators) which ~~are known to~~ have a laminar structure with alternating electrode layers and layers of piezoelectric material. ~~(therefore are also referred to as "laminar" piezo actuators).~~ This arrangement has the advantage that the electrodes are integrated into the piezo actuator, which greatly facilitates contacting of the piezo actuator and at the same time ensures a homogeneous field distribution within the piezo actuator. It is especially expedient that the electric field for inducing the d33 effect is supplied via the electrodes integrated into the laminar piezo actuator. The ~~inventive arrangement~~ invention can therefore be implemented especially effectively and in a technically simple manner.

[0016] Furthermore, it is expedient for the laminar d33 piezo actuators to have a low thickness [[of]] (approx. 0.5 to 2.5 mm) so that they have hardly any influence at all on the flow conditions. It is advantageous that such thin-layered d33 piezo actuators can ~~easily~~ be introduced or integrated easily into the shells of aerodynamic profiles, and have a low weight.

[0017] Furthermore it is expedient that the side dimensions of the d33 piezo actuators are between 5 and 60 mm. This permits easy adaptation to given geometries (*e.g.*, corners, edges, rounded shapes, etc.).

[0018] The ~~inventive principle is used mainly~~ invention can be used, for example, in helicopter rotor blades, aircraft wings, turbine blades or the like.

[0019] Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

~~This invention is explained in greater detail below on the basis of the accompanying figures, in which:~~

[0020] ~~FIG 1 shows~~ Figure 1 is a schematic three-dimensional view of an aerodynamic profile with d33 piezo actuators; [[,]]

[0021] ~~FIG 2~~ Figure 2a) is [[shows]] a schematic diagram of a stacked piezoelectric element ~~to illustrate~~ which shows [[a)]] the d33 effect, which Figure 2b) shows ~~and b)~~ the d31 effect;

[0022] ~~FIG 3 shows~~ Figures 3a) and b) are schematic views [[to]] which illustrate a torsional convexity ~~on the basis of a) a~~ partial cross-sectional [[view]] and top views of a shell, respectively; [[and]]

~~b) a top view of the detail shown in FIG 3a;~~

[0023] ~~FIG 4 shows~~ Figure 4 is a sectional view of another embodiment of an ~~inventive~~ aerodynamic ~~profile~~ profiled member according to the invention; and

[0024] ~~FIG 5 shows~~ Figure 5 is a schematic three-dimensional view of an aerodynamic profile with the control flap connected by an articulated joint.

DETAILED DESCRIPTION OF THE DRAWINGS

[0025] ~~FIG 1 shows in general form~~ Figure 1 is a schematic depiction of an aerodynamic ~~profile~~ profiled member, 1 which ~~in a schematic three-dimensional diagram. The profile 1~~ has a front profile area 2 and a rear profile area 3 situated on the downflow side ~~. To illustrate this, FIG 1 shows~~ (in the direction of flow [[with]] illustrated by the arrow S_{flow}). The profile 1 is bordered in a known way by a shell 4 on the pressure side and a shell 5 on the suction side, ~~converging~~ which converge in a rear profile edge 6 in the rear profile area 3. The rear profile edge 6 runs in the width direction S_{width}. Such an aerodynamic profile 1 may be, for example, a helicopter rotor blade or an aircraft wing, both of which are well known in the state of the art, so that no further description of individual details is needed here.

[0026] The aerodynamic profile 1 is also provided with piezo actuators 7, which are arranged on the shell 5 (on the suction side in the embodiment according to FIG 1). The actuators may of course also be provided either additionally or exclusively on the shell 4 on the pressure side, depending on the demands of the application. The piezo actuators 7 are attached to the shell(s) by

gluing or by [[using]] other fastening means (e.g., clapping devices, screwing devices, etc.).

[0027] These piezo actuators 7 have the so-called d33 effect (longitudinal effect), which is explained in greater detail in conjunction with FIG 2. FIGS 2a and 2b ~~show in~~ are schematic diagrams which show a stacked piezoelectric element 8 (also known as piezo stack) which is constructed of alternating layers of electrically conducting material and piezoelectric material, as is already known. The layers of electrically conducting material are electrodes 8a. In ~~the case shown in~~ FIG 2a, the electric field E runs in the stack direction and/or the longitudinal direction of the piezoelectric element 8, with the electric field E expediently being provided by the electrodes 8a. ~~Because of the~~ The electric field E [[,]] causes the piezoelectric material ~~expands~~ to expand in the direction of the electric field E. This change in length is labeled as ΔL in FIG 2a. It [[and]] is known to be greater than the change in length Δl in the d31 effect, in which the change in length Δl occurs across the electric field E (see FIG 2b).

[0028] The piezo stack 8 shown in FIG 2a ~~has been~~ is cut in the longitudinal direction (shown by the broken lines) for use as d33 piezo actuators 7 for the aerodynamic ~~profile diagrammed schematically~~ profiled member in FIG 1. The [[; the]] laminar structure with alternating layers of piezoelectric material and electrically conducting material is retained. The thickness d of the piezo actuators 7 cut in this way typically amounts to 0.5 to 2.5 mm and the side dimensions a and b are typically between 5 and 60 mm.

[0029] The arrangement of the cut laminar d33 piezo actuators 7 on the aerodynamic profile 1 is based on the application, so the profile curvature can be varied in the desired direction. ~~This is explained again in greater detail below with reference to FIG 1.~~ Thus, FIG 1 shows as an example three d33 piezo actuators 7 arranged in the front profile area 2, ~~. The d33 piezo actuators 7 are~~ aligned so that [[the]] their change in length ΔL when ~~the d33 piezo actuators 7 are~~ acted upon by electricity within the shell 5 takes place in the direction of flow S_{flow}, ~~which is~~ as indicated with the double arrow A ~~in FIG 1~~. In addition, the d33 piezo actuators 7 may also be arranged in such a way that their change in length takes place ~~in the plane of the shell 5~~ in the width direction in the plane of the shell 5 ~~, which is~~ (represented by the actuator 7, arranged near the rear edge 6). The direction of the change in length of this actuator is labeled with the double arrow B here.

[0030] The piezo actuators 7 may of course also be arranged in such a way that the change in length within and/or parallel to the planes of the shell ~~points~~ is oriented in a direction between the directions A and B (not shown in FIG 1). Minor deviations, [[e.g.,]] due to for example incomplete fastening of the piezo actuators ~~the fact that it is not fastened completely~~ flatly on the shells (*i.e.*, they ~~the piezo actuators~~ are at a slight inclination with respect to the planes of the shells) are harmless, and are within the range of tolerance. It is essential here that the d33 piezo actuators [[are]] be arranged in such a way that their change in length, when acted upon by electricity, runs essentially in the direction of the

planes of the shells 4 and/or 5. Corresponding changes in length in the plane of the shells 4, 5 (and thus curvature) can be achieved in this way.

[0031] ~~For the case when~~ When torsion of the aerodynamic profile 1 is desired, the d33 piezo actuators 7 are arranged in a similar manner on both sides of the respective shell 4 and/or 5, ~~which is~~ as explained ~~in greater detail below~~ with reference to FIGS 3a and 3b. FIG 3a shows as an example a partial cross-sectional view of the shell 4 on the pressure side with d33 piezo actuators 7 attached to its top and bottom sides 4a, 4b. As described previously, the d33 piezo actuators 7 are arranged in such a way that their length changes essentially in the direction of the plane of the shell when acted upon by electricity, they undergo a change in length essentially in the direction of the plane of the shell. The piezo actuators 7 on the top and bottom sides 4a, 4b, however, have a different orientation with respect to one another, as depicted in FIG 3b ~~, which is~~ (a top view of the detail shown in FIG 3a). The d33 piezo actuators 7 arranged on the top side 4a points in a direction A' within the plane of the shell 4, and the piezo actuators 7 (shown with dotted lines) arranged on the bottom side 4b points in a direction B'. Due to this "crossed" arrangement, torsion is induced in the respective shell on actuation of the piezo actuators 7.

[0032] According to another embodiment ~~, which is~~ (not shown) [[here]], the thin d33 piezo actuators 7 can be integrated into the shells 4, 5 on the pressure side and/or on the suction side. Such a design is beneficial, for example, when the shells are made of composite materials. Due to the integration of the piezo

actuators into the composite structure, the actuators 7 are protected, while on the other hand the most symmetrical possible curvature is achieved. The latter is advantageous in particular when the shells have a relatively great thickness in relation to the actuator thickness d. Such an integrated arrangement is typically used with composite structures (*e.g.*, metallic composite structures, MMCs, fiber composite materials, etc.).

[0033] In a special embodiment of this design, which is depicted schematically in FIG 4, the shells are not designed separately of a composite material but instead the entire profile is designed as a composite material. In this case the aerodynamic profile 1 is not hollow. Instead, it ~~but instead~~ has a compact design and the piezo actuators 7 are arranged inside. (A ~~the profile 1, a~~ piezo actuator 7 [[being]] is depicted only schematically in FIG 4.)

[0034] ~~Furthermore it should be pointed out that the~~ The active principle of this invention can also be applied similarly [[for]] to other ~~profiles~~ profiled elements that are exposed to oncoming flow and are mounted on the aerodynamic profile 1, for example. This is indicated schematically in FIG 5, ~~showing~~ which shows an aerodynamic profile 1 [[which]] that has another oncoming flow profile pivotably hinge-connected to its rear profile edge 6. For deflection and/or curvature of the flap 9, the d33 piezo actuators 7 are mounted on the flap 9, ~~in this exemplary embodiment, whereby~~ so that the change in length of the d33 piezo actuators when they are acted upon by electricity takes

place in the direction of the plane of the flap 9, [[like]] <u>as is the case with</u> the arrangement described in conjunction with FIG 1.

<u>[0035]</u> In each of the embodiments described above, the piezo actuators 7 may be sheathed with electrically insulating material (*e.g.*, ceramic, polymer, etc.) completely or only at the interface with the structure (*e.g.*, shell 4, 5 on the pressure side or on the suction side) or ~~{coated}~~ <u>coated</u> to ensure insulation of the structure. This is relevant in particular when the structure to which the piezo actuator is applied is electrically conducting. Similarly, such a sheathing may also be used for protective purposes.

<u>[0036]</u> The stacked d33 piezo actuators used here may be supplied with electricity via the electrodes 8a in a simple manner, as described above. The operating voltage is typically in the range of 50-500 V and contacting of the electrodes 8a can be accomplished through soldered connections or bus connections that are technically easy to implement.

<u>[0037]</u> The inventive principle explained above is <u>described as</u> used ~~mainly~~ in the curvature of helicopter rotor blades, aircraft wings, turbine blades or similar applications. However, use of the inventive idea is not limited to these specific examples.

<u>[0038]</u> <u>The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur</u>

to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.